Report Covering the Course of the Programme

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REPORT COVERING
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1. INTRODUCTION

This report briefly describes the course of the framework programme "High Performance Concretes in the 90'es", which had been started in the summer of 1989 and finished at the end of 1992.

The report has been prepared after the instructions which are described in "Proposal to terms of reference for the final evaluation of framework programmes under The Material Technological Development Programme" dated March 23, 1992 prepared by the Industrial and Commercial Management.

The programme covers 10 projects which are described in more detail in the following. By way of introduction it is mentioned that project 4, see section 4.4, Fracture Mechanics for Concrete, has had technical connection to the programme, but it is not financed by the programme.

2. PURPOSE AND ACTIVITIES

The subject of the programme is high performance concretes in the 90'es and the main purpose is to contribute to improve the new qualities of the concretes both in the production phase and in the final construction.

The main idea in the programme is that it gives a number of results, which however are useful in practise. Besides, a number of investigations have also been included, which, if they are fruitful, also will be of great importance, but which at present have a character of research.

Concrete is one of the most useful structural materials inside the building technique and is practically used in all kinds of constructions, as e.g., small houses, tower blocks, industry, bridges and off-shore structures. In the future to come there is no prospect of new materials which might replace concrete. This is due to the low price of concrete and its unique qualities regarding workability (the construction can be given almost all kind of shapes) and designability (the qualities of concrete can be chosen inside a very great spectrum of possibilities).

An improvement of the economy about the use of concrete will therefore have a greater effect on the society than what will be for the most other materials.

For a long time concrete has been able to be produced with different kinds of qualities, but during recent years it has exceeded the limits of which you earlier thought was possible. Concrete can to-day be produced with compressive strengths which corresponds to strength of steel, and many different qualities can be obtained by means of various additives, fibres etc. On account of this it is reasonable for the next decade to characterize the concretes as a new material in Danish industry.

Concrete with a high strength which normally is produced by adding super-plasticizers and micro-silica and/or fly ash, is used in a still larger extent abroad, and it has to be expected that in the 90'es in Denmark high strength concrete will also be used considerably.

Abroad, especially in the U. S. A. high strength concrete is used for tower blocks constructions with the simple purpose to reduce the concrete dimensions.

In Norway stronger and stronger concrete is used for off-shore constructions, which are built up by complex shell constructions carried out in strongly reinforced high strength concrete.

In France an interesting development inside the bridge area is going on. New types of bridges based on the utilization of high strength concrete together with pre-stressing cables lying outside on the construction have turned out to be very competitive. This is due to the fact that this kind of construction gives a lower net weight, which is an important factor for great bridges.

Also in Denmark concrete with high strength is used in an aggressive environment in the interests of the durability, while it is still seldom that the strength of the concrete is used in the calculations.

Correspondingly, there is a rich development going on concerning additives, fibres etc. For example by using a super-plasticizer a concrete with a lower water-cement-ratio and higher workability than ever known can be produced. By addition of polymers, latex etc. the concrete qualities can be changed in a favourable direction concerning frost resistance, wearability etc. By addition of fibres the ductility of the concrete can be very much improved, and plastic shrinkage with a resulting formation of cracks can be prevented.

However, the strong concretes and the classic concretes modified by means of additives, fibres etc. have in many ways qualities which differ from those from the traditional concrete. Therefore, it is extensively necessary to repeat the theoretical and the experimental research which for many years has been carried out on the traditional concrete. Some of the qualities which are the most important to know more about concerning the strong concretes and the modified concretes, has been examined in this programme.

The strong concretes and the modified concretes with a high documented quality are together called high performance concretes.

The investigations will include concrete in the area going up to compressive strengths of 100 MPa, which is the area that is the most relevant in the years to come. The examined qualities are:

Durability	Frost resistance
	Chloride resistance
	Influence of temperature and humidity
	Influence of cracks
	Influence of additives, fibres etc.
Production	Curing technology
	Effect and control of air content
Mechanical properties	Brittleness (fracture energy)
	Multiaxial strength and stiffness of concrete

	Fatigue strength, long-term strength Influence of cracks Properties in early age Influence of temperature and humidity
Structural improvement	New types of structures Use of new materials as pre-stressed reinforcement

The investigations are carried out in 10 projects:

Project 1: Frost resistance of high performance concretes
2: Chloride penetration in concrete under load.
3: The qualities of concrete at an early age
4: Fracture mechanics for concrete
5: Qualities of high strength concrete in multiaxial loading
6: Fatigue of high strength concrete
7: Strength of cracked concrete
8: Structural considerations in connection with high strength concrete
9: Demands for concrete cover for high performance concretes
10: New materials for pre-stressed concrete constructions

In connection with the application in 1989 to the Industrial and Commercial Management a more detailed description of the content for the single referred projects is enclosed. Furthermore, it is referred to chapter 4 in which the results for the individual projects are mentioned.

Besides, common features of the projects are:

- that it is attained that information from the literature is tried to be evaluated and operationalizised by implementing of analytical models,
- that new material data have been produced and described at a fracture mechanical and stochastic basis, where it is relevant
- that the models are tested by use and on constructions.

In all the projects in the programme the same standard procedure for concrete mix has been used. The components in the concrete mix are all available in Denmark.

3. ORGANIZATION AND RESOURCES

In the programme the following institutions and firms participate:

- The Department for Structural Engineering, Technical University of Denmark (ABK)

- The Department of Building Technology and Structural Engineering, University of Aalborg (IFB)
- Spæncom (earlier A/S Dansk Spændbeton). Manufacturer of prefab concrete elements.
- Rambøll, Hannemann & Højlund A/S (earlier Rambøll & Hannemann A/S) (R, H & H). Consulting Engineers.
- AEC, Rådgivende Ingeniører A/S (AEC). Consulting Engineers.

The first "official" meeting in the programme took place on 14.08.89, where K. Evald, Spæncom, was elected chairman and M. P. Nielsen, ABK/AEC was elected programme leader.

On the 14.08.89 the following persons worked as the steering group :

K. Evald, Chairman
M. P. Nielsen, Programme leader
Erik Lind, Spæncom
Eilif Svensson, R, H & H
Lars Pilegaard Hansen, IFB

The steering group was primo 1990 supplemented with P. Nepper-Christensen, Aalborg Portland, and from the middle of 1991 K. Bagge, R, H & H replaced Eilif Svensson.

Totally 19 meetings have been held.

The management of the individual projects is managed by a project leader.

For each project a consulting group was formed covering representatives from institutions, consulting engineerings, producers etc. from home and abroad.

A list of the project leaders and the consulting groups is given in enclosure A.

Totally the steering group and the project leaders have had 6 joint meetings.

Furthermore, two "days of high strength concrete" have been held at the Technical University of Denmark on 12.09.90 and 10.10.91. On these meetings the project leaders and project members of some of the projects told about their work. Both arrangements were well-attended.

In connection with the programme 4 Ph.D. studies have been started, and all of them are expected to be fulfilled and ended.

The programme appropriation was an amount of 9 million DKK, and the distribution on the different projects appears from the final accounts of the programme, to which reference is made.

In connection with the "Teknovision" exhibition in Copenhagen in the summer of 92 an "experimental bridge" with a span of 30 m has been built. After the exhibition DSB (Danish Railways) has used the bridge as a bridge for pedestrians. See chapter 4.8.

Another bridge built in connection with the Jutland Motorway has also been part of the programme, see chapter 4.8.

In connection with the programme a database covering approx. 750 references of high strength concrete has been implemented in a DBase III Plus programme.

A laboratory testing machine for multiaxial testing of concrete has been purchased and used for the tests in project 7, see chapter 4.7. This testing machine is now at ABK.

4. OBTAINED RESULTS AND RESOURCE CONSUMPTION

In this chapter a description of the single projects are given.

The publications which are finished at the end of 1992 for the 10 projects are stated in enclosure B.

In connection with e.g. project 6 and 8 further publications will turn up in the beginning of 1993.

4.1 Frost Resistance of High Performance Concretes

Project leader Jens M. Frederiksen, AEC

Project members Majbritt Herold, Ernst de Place Hansen, Torben Seir Hansen, AEC

The following work has been done:

Preparation of the State of the Art report for frost resistance of concrete (report 1.1); theoretical work with models for air buble distributions; theoretical work with continuum mechanical model for frost destruction; theoretical work with a model for simultaneous temperature, humidity and chloride penetration in concrete; test planning for successive investigation of frost destruction; carrying out of frost testing; thin section production.

Theoretical work with a fracture mechanical frost model together with development of edb-programme of this (report 1.2 in preparation). Experimental work with measuring of pore size distribution in high performance concrete by means of measuring of desorption isotherms.

Looking in the literature it turns out that there was lacking experiments with non-air-entrained high performance concrete. Laboratory testing indicated a really good frost resistance of high performance concrete in the project. The theoretical models that are developed indicate that compact structures will not be frost destroyed. Important parts of the projects have not been finished yet, as the necessary extra appropriation has not been given.

4.2 Chloride Penetration in Concrete under Load

Project leader Jens M. Frederiksen, AEC

Project members Henrik Erndahl Sørensen, Ervin Poulsen, AEC

The existing knowledge within the area has been summarized in report 2.1. This report has been made in the light of an extensive literature search. A data bank covering literature about this subject has been made, and on the basis of this a bibliography has been made which is reported in report 2.2. With the background in the literature investigation a test planning has been prepared which is reported in report 2.3 (in print).

With the purpose of examining the effect of cracks produced by load reinforced concrete specimens with and without cracks with reference to the test planning have been produced. These specimens are staying for outdoor exposure in the yard of the AEC laboratory and are daily poured with concentrated NaCl-dissolution. Reliable results of these tests are expected earliest after an exposure of 5 to 10 year.

Besides the three reports in the report series of the frame programme the obtained experiences within this subject have been published in the following articles:

Dansk Betondag 1990
Dansk Beton nr. 2 og 3 1992
Nordisk Betonforskningsmøde 1990
Nordic Concrete Research 1991

4.3 The Qualities of Concrete at an Early Age

Project leader	Bemt Andersen, AEC
Project members	Ole Høyer, Per Kastrup Nielsen, Henrik Elgaard Jensen, Flemming Lindbæk Kronholm, AEC

Production of high performance concrete is not a question of ensuring that the concrete will get a high strength.

It is important to ensure everywhere in the production process that the concrete will not get an unintended weaknesses.

The purpose with this project is – in the light of existing literature supplemented with a comprehensive test series, where the qualities of young concrete have been measured - to develop on the stage of hardening technology.

During recent years there has been worked with the problem in Denmark. To avoid thermo-cracks you often delimit how great the temperature differences must be during the hardening process. The model behind these limits is very rough and sometimes has turned out to be on the safe side and sometimes on the unsafe side.

After an introductory literature study a great test series with the two concrete recipes which are general in this framework programme has been carried out.

Some measurements have been made, how the strength of the concrete (both compressive and tensile strength) is developing eventually. Performance curves for both tensile and compressive strength have been measured at different maturities. Furthermore, it has been investigated what an influence creeping and self-draining has. To investigate what an effect the temperature during the hardening process has tests at 3 temperature levels at 20°C, 37,5°C and 50°C have been made.

Testing the qualities of concrete it is common to water store the test specimens until the test. To "copy" practice where it is generally impossible for a humidity change with the surroundings, sealed test specimens have been used in this project. Some of the tests have also been carried out at water stored specimens to be able to compare with "traditional" tests.

In connection with planning and carrying out of an experimental bridge under project 8 (chapter 4.8) a programme for hardening process and treatment under project 3 has been made.

At the start of the project it was the hope that in the light of new investigations to be able to reach a stage, on which you by mathematical modelling of the hardening process and qualities developments are able to determine a set of control intervals, inside which the concrete production and treatment are to be. This has not been possible inside the economy of the project.

Besides hardening technology rheology of the new concrete has been studied. This part of the project ended in a "State-of-the-art report".

4.4 Fracture Mechanics for Concrete

Project leader Rune Brincker, AUC

Project member Jens Peder Ulfkjær, AUC

The high performance concretes which have been developed during late years are concretes which differ a lot from the traditional concretes with reference to qualities which control the crack development. Therefore, it has been important to develop models which describes the crack growth for these brittle concretes. In order to have such a model to be describing for real constructions, it is necessary to include extra material parameters (f.ex. fracture energy) together with the size of the construction (normally, it is only the proportional size which is important). In this project development of analytical and numerical modelling are focused, where these two facts are considered for unreinforced and weakly reinforced high strength concrete. In this way a numerical algorithm and a simple analytical model, which describe the crack growth in beams, have been developed. Furthermore, an extensive series of experiments have been carried out in a new-developed servo-controlled test arrangement. The test results show that even with advanced models it is not possible to avoid size effects on the material parameters. The project had been finished on 31.01.92 with a fine result where the project member defended the Ph.D. study which has been made in connection with the project.

4.5 Qualities of High Strength Concrete in Multiaxial Loading

Project leader M. P. Nielsen, ABK/AEC

Project members Kaare K. B. Dahl, Henrik Elgaard Jensen, ABK

To be able to design concrete constructions in high strength concrete it is necessary to know the strength at uniaxial, biaxial and triaxial conditions and it is also necessary to know the shrinkage and creeping conditions. Knowledge to the strength at multiaxial conditions occurs f.ex. by the calculation of strength and strain capability wrapped in confinement, by calculation of cable anchorage in pre-stressed concrete constructions and by punching shear, f.ex. of slabs at concentrated loads.

Especially, the work in project 5 has been experimental. The tests carried out make at the time the greatest test series in the world.

The triaxial tests show that you cannot extrapolate the well-known fracture conditions to high strength without making great mistakes. The work is utilized in two proposals. The first one relates to the modifications of the very often used Coulomb's fracture condition which is also used in soil mechanics. If this has to be used it is necessary to work with a "two stage" model, at which cohesion and angle of friction change value by changing from one region to another.

The other proposal describes the necessary modifications by using the Ottosen's fracture conditions.

At the shrinkage and creep tests which have been carried out, it has been shown, how high strength concretes which will be typically in Denmark will shrink and creep. Recommended curves for shrinkage and creep as a function of the compressive strength have been made (even though this, strictly speaking, is not a sufficient characteristic of a concrete in relation to shrinkage and creeping conditions).

4.6 Fatigue of High Strength Concrete

Project leader Lars Pilegaard Hansen, AUC

Project member Niels Bo Sørensen, AUC

During recent years fatigue in connection with concrete constructions has been a current problem. It is due to the fact that by means of higher strength a load distribution has been obtained, where the net weight still make a smaller part in proportion to the variable (dynamical) load. F.ex. this has been the case for off-shore constructions and for large bridges. Therefore, it is of vital importance to know the fatigue qualities of concrete.

In this project a very comprehensive test series has been carried out in order to provide lifetime data for high strength concrete exposed to constant amplitude compression.

Maximum and minimum load level, frequency and load rate are among the examined parameters. The analysis has included:

<u>1. Description of lifetime data</u>
Under this the variation of S-N data has been analysed and the qualities of different models for description of S-N data has been investigated.

2. Damage accumulation and qualification of different "damage parameters" as indicators of the fatigue process

During the tests the development of damage has been followed through measurements, by means of strain gages. The following measurements have been used as indicators of the fatigue process:

- axial strains
- transverse strains
- volume strains
- tangent E-modulus
- axial rate of strain
- transverse rate of strain

Especially, rates of strain are promising as an indication of lifetime. Based on this observation it is shown that the variation in S-N data can be reduced drastically. As something new the relation between the lifetime and the rate of strain was used to estimate the lifetime during the test. By this it was possible to obtain data of strength (and stiffness) reduction during the tests.

3. Analysis of crack formation under fatigue

In different kinds of stages of the fatigue process thin section has been analysed by means of digital image processing (carried out by Henrik Stang, ABK). The results will soon be available.

4. Establishment and evaluation of a fatigue model, where concrete is considered as a defect visko-elastic material

Based on Lauge Fuglsang Nielsen's (The Laboratory of Building Materials, DtH) works on wood a lifetime model is described, its starting point is discussed and the quality of the model for description of the fatigue data for high strength concrete are evaluated.

4.7 Strength of Cracked Concrete

Project leader	M. P. Nielsen, ABK/AEC
Project members	Henrik Elgaard Jensen, ABK, Kaare K. B. Dahl, ABK, David Holkmann Olsen, ABK, Lars Juel Rasmussen, ABK, Thomas Cornelius Hansen, ABK, Ding Dajun, China, Liu Weiqing, China

The strength of cracked concrete has a fundamental importance to almost all stiffnes and carrying capacity problems within the concrete construction area. It is due to the fact that concrete always is cracked on the micro crack plan, even before loading, and that the crack development during the loading f.ex. for fracture has a great importance to both stiffness and the final carrying capacity.

In order to estimate the remaining strength of the damaged constructions knowledge to the strength of cracked concrete is of course of very great importance.

Systematical studies of cracked concrete strength are still rare. Vejdirektoratet (The Danish Road Authority) has made a great planned project about the carrying capacity of alcali-silica damaged bridges. It is here shown that the strength at shear, interlocking and anchorage do not fall as much as the uniaxial compressive strength on account of the cracks. That accounts for the fact that cracked concrete in a way is a more plastic material than uncracked concrete on account of the possibilities of slidings in the cracks, so that greater stress changes in a favourable direction are possible compared to uncracked concrete.

In the project a more fundamental study of the behaviour of cracks has partly been carried out, partly practical investigations have been continued about the influence on strength of different crack formations.

There has been developed a new quite fundamental theory for the crack growth, which has resulted in a crack growth formula, that is a formula that states how a crack grows as a function of the given loading or deformations. The formula is verified for metals, for which a lot of test results (steel, aluminium etc.) are available and for unreinforced concrete under the three-point loading and uniaxial tensile. A fine harmony has been found between the theory and the test results.

The test about the shear strength of a crack as a function of the concrete compressive strength and the reinforcement that passes the crack has been carried out. The test results are limited but it looks like the plasticity theory as in many other areas can be used as a theoretical frame.

Finally, tests with construction joints and with the compressive strength of slabs with cracks under different angles with the pressure direction have been carried out.

The tests carried out seem to show that a crack can be treated as a special "material" within the frames of the plasticity theory, as only reduced strength parameters have to be introduced. Unfortunately, it has not been possible inside the given frame of appropriation to finish this project. For a smaller extra appropriation the obtained results could be published more completely, but such a appropriation has not been possible to obtain in spite of several applications.

4.8 Structural Considerations in Connection with High Strength Concrete

Project leader	Mikael W. Bræstrup, R, H & H
	Besides collaborators from R, H & H, AEC, ABK and Spæncom A/S have participated.

The purpose of the projects is to investigate the use of high strength concrete for new constructive purposes as well as for traditional constructions.

The project was divided into four subprojects:

1 Material properties
Responsible: ABK/AEC

2 Minimum reinforcement
Responsible: R H & H

3 Structural forms
Responsible: AEC/Spæncom/R H & H

4 Early deforming
Responsible: Spæncom/AEC

The technical work with this project started in the spring of 1990 and was expected to be finished at the end of 1992 (ref. to the report from the steering group meeting No. 16, 1992.05.12). On June 30, 1992 about 35% (DKK 360,000) of the estimated funds was remaining, but on account of budget exceeding other places in the frame programme the work was put to an end at this moment. Therefore parts of the planned work have not been finished or documented. A brief report of the work carried out (subproject 2 and 3) will demand resources in the size of DKK 30,000 (ref. to report of project leader meeting of 1992.08.26).

At any rate, a summary report concerning subproject 2 (Minimum Reinforcement) is planned by R, H & H during early 1993.

In the following a final status for the single subprojects is given.

1 Material properties
Report 8.1: "State-of-the-Art Report on Material Properties of High Strength Concrete has been published (March 1992)

Report 8.4: "Torsion of reinforced normal and high strength concrete beams" has been published (June 1992)

2 Minimum reinforcement
Commented draft of the report 8.2 part I about minimum reinforcement of concrete is available.

Report 8.2, part II, about theoretical modelling of minimum reinforcement of normal and high strength concrete is being prepared.

3 Structural forms
Commented draft of the report 8.3: "Structural Forms for High Strength Concrete" including special sections about the element constructions is available

4 Early deforming
This subproject is included in subproject 8.3 in the form of a section about concrete elements, ref. to the above-mentioned.

The results have found utilization, as specifications of high strength concrete for a bridge to Vejdirektoratet (The Danish Road Authority) (Stobdrupvej) has been prepared, (see the following) as well as a bridge to pedestrians for DSB (Danish Railways) (Lunderskov) has been made. This bridge was before the delivery placed in Copenhagen in connection with DIF's jubilee exhibition Tekno Vision.

As a part of project 8 some work has been done with an experimental bridge at Randers, as mentioned. This part project is described in the following.

Experimental Bridge - Use of High Performance Concrete

Project leader Henrik Mørup, AEC

Project members Ervin Poulsen, Jens M. Frederiksen, AEC

In conncetion with the building of the Jutland Motorway (the stretch Hadbjerg – Randers south) a lot of overpasses of the local road system have been made. The last one of these overpasses is the bridge 70-0030 of Stobdrupvej, which has been made of concrete with a demanded characteristic compressive strength (f_{ck}) at 75 MPa. The bridge design is as for a normal bridge concrete with a f_{ck} > 35 MPa, i.e. that the higher compressive strength has not been used constructively, as the purpose primarily was to get experiences with this type of concrete under common building site conditions.

Vejdirektoratet has paid the additional price for the concrete corresponding to the normal concrete control at motorway bridges. The framework programme has contributed at the preparation of the concrete description and the supply material, and the further performance among other things in the shape of support to concrete proportioning and planning of the pouring time and after treatment arrangements. Furthermore, the framework programme has contributed with the carrying out of the more stringent control arrangements, f.ex. at the control test of the concrete in the construction at the extension test (compressive strength measure) and structure analysis.

Results: At the formulation of the concrete description benefit from the projects 1 and 2 of the framework programme has been derived. As an example the concrete has not been air-entrained realizing that high performance concretes cannot be frost damaged in the laboratory. Costs of maintenance for this bridge must be considered to be much lower than those of the other bridges at the stretch, which is motivated with the impermeable concrete that is used. At the comprehensive measuring programme of the hardening process of the concrete a data bank which f.ex. can be used by estimation of the accuracy of multidimensional temperature programmes is established.

Vejdirektoratet has promised a support for the carrying out of a report (for publishing) about this experimental bridge.

4.9 Demands for Concrete Cover for High Performance Concretes

Project leader Erik Lind, Spæncom

Project members Ervin Poulsen, AEC

Rebars, non-resistant to corrosion, must have a suitable concrete cover in order to protect them against corrosion during the intended lifetime of the structure. The depth of the rebar cover is determined according to practical experience and required by the Code of Practice.

A proposal of introducing a required minimum of rebar cover was put forward during the public evaluation of the first Code of Practice in Denmark which came into force in 1908.

However, this was not accepted for unknown reasons, while the proposal in 1921 for a new edition of the Code of Practice included requirements for the rebar cover in relation to the environment classes.

The 1930-edition of the Code of Practice introduced the well-known 1-2-3 cm rule for the rebar covers. With some interpretation revisions this simple rule is still valid. It is notable, because the Codes of Practice in the UK and the USA introduced a corresponding 1-2-3 inches rule for the rebar cover at the same time.

Fundamentals are listed for the requirements of the depth of rebar covers on condition that the rebars are of the non-resistant type. This is done in close connection with the Danish Working Committee on the same topic and committees abroad.

Preparing a code of practice always calls for a specification of the numerical values of certain parameters important to the function, safety and durability of the structures. These parameters depend on:

* Properties and characteristics of the concrete.
* Models of the durability and disintegration of concrete.
* The quality of the concrete workmanship.
* The consequence of failure.
* The intended lifetime.

Depth of cover of rebars must at least depend on the intended lifetime, the consequenses and types of corrosion and the quality of concrete and reinforcement.

Durability requirements cannot be decided by a "show of hands". Non-relevant parameters may get an influence which is by no means documented. As an example it could be mentioned that at a recent voting by "show of hands" the maximum size aggregate of the concrete got a predominant influence. The maximum size aggregate certainly has an influence, but with much less significance than e.g. the enviromnent and the concrete work; this has not been documented elsewere anyhow.

To-day the neccessary probabilistic tools exist enabling a risk-analysis to be carried out. Thus, probability analysis is advisable. By this method it is possible to obtain well-founded requirements for the durability of rebar covers based upon available and documented information according to the teachings of concrete technology and durability.

As a conclusion it is demonstrated and well documented by the committee that a probabilistic design method is a very applicable method for the determination of the depth of the rebar cover in a given situation. The depth of rebar cover can be designed at a certain safety level by means of the probabilistic method to resist the following:

* Corrosion by carbonation.
* Corrosion by chloride ingress.
* Failure against fire.
* Failure against lack of anchorage and bond.

In order to apply the method of probabilistic design of depth of rebar cover one has to fix the level of safety. This safety level may as well be defined by a calibration against known and acceptable cases.

The described probabilistic design method should be applied to resistant rebars by not taking durability into account.

4.10 New Materials for Pre-stressed Concrete Constructions

Project leader Kuno Evald

Project member Finn Theilgaard

The project was divided into 3 phases - analysis, test and conclusion. The analytical phase was the preparation of the report 10.1. The status report describes the most important materials, the qualities (great strength, corrosion resistance, electro-magnetic neutrality etc) and the use of them so far.

In the light of this report the material Arapree was elected for a further test. 4 test elements, which show that the general known pre-stressing technique also can be used at fibre lines have been poured. A further test series which was going to show the bearing capacity, fracture shapes etc. has not been carried out.

A total conclusion of the project cannot be carried out, but a part conclusion on the background of the status report and the test pouring will be that for special purposes there is a potential for the use of fibre lines. These purposes will be structures inside the high corrosive areas or thin slab constructions, where demands for final coat are neglected.

5. DEVELOPMENT IN THE FUTURE

As it is shown from the description of the 10 projects in chapter 4 a great work to describe the qualities of high strength concrete has been carried out.

On account of various resources some projects have of course come a little longer than others, but generally, it applies that for all projects the work can go on with the results that are available from this programme.

On 17.09.92 the steering group has sent in some proposals of new activities for a new framework programme (enclosure C. (in Danish)). This programme will mainly be of experimental character and practical aspects will have a central position. I.e. the programme will include structures with a main reinforcement of fibres, just as an investigation of concrete structures in earthquake areas and use of high strength concretes for offshore structures will be illustrated. There has been calculated on a programme period of 4 years and a budget of about 2 million DKK a year.

Besides, some of the members of the framework programme have sent in an application to a programme with the title "Material models for structures", where 3 single projects all about concrete structures are described. The single projects are

* Ultimative strength of concrete joints at combined actions.
* Development of different types of joints, especially for use in earthquake areas.
* A further development of models for description of the qualities of (cracked) concrete.

The programme includes both theoretical and experimental investigations, and has been proposed as a programme of 4 years to a total of about 4 million DKK.

Furthermore, it is the hope of the members of the steering group that the results which have been made through the framework programme will be used in the future development of concrete structures, where high performance concrete is used.

6. CO-OPERATION BETWEEN THE PARTICIPANTS IN THE PROGRAMME AND OTHER GROUPS

As it is shown from chapter 3 and enclosure A there has for each of the 10 projects been a consulting group consisting of the project leader and a number of members (3–6) from home and abroad.

Through this the framework programme and the results of this has had the possibility to come out to a great deal of other researchers and users. It is assessed that the idea is good to form such consulting groups. At the same time it has to be stated that it can often be difficult to get the group to work perfectly, i.e. on account of time problems, geographical distances, financial circumstances, and so on.

As it is shown from enclosure A the following institutions and companies have been represented in the consulting groups:

CtO, Aalborg, Danmark
The Laboratory of Structural Materials, DtH, Danmark
Lunds Universitet, Sverige
DSB, Danmark
Korrosionscentralen, Danmark
Storebæltskonsortiet, Danmark
G. M. Idorn Consult, Danmark
Cementa, Finland
Danmarks Ingeniørakademi, Danmark
CBL, Aalborg, Danmark
Chalmers Tekniske Högskole, Sverige
Cowiconsult, Danmark
Vejdirektoratet, Danmark
Rasmussen og Schiøtz, Danmark
Bouygues, Frankrig

SINTEF, Trondheim, Norge
Dansk Teknologisk Institut, Danmark
Axel Nielsen (Carl Bro), Odense, Danmark
Risø, Danmark
Tekniska Högskola i Luleå, Sverige
Skandinavisk Spændbeton, Danmark
Højlund Rasmussen, Danmark

7. OTHER CONTACT GIVING ACTIVITIES

The steering group of the framework programme has on several occasions discussed how the results can be effected to the surrounding world in the best way.

Furthermore, the problem was made topical in 1991, where the Industrial and Commercial Management asked for some thoughts and ideas about the communication effort.

In the framework programme there has been a lot of work with this problem, which resulted in a smaller note (in Danish), and a letter dated 28.08.91 was sent to the Industrial and Commercial Management. The letter and the note (without any enclosures) are enclosed as enclosure D.

However, from the Industrial and Commercial Management we have not received any support to the ideas, which are described in the note, and unfortunately we have to face to fact that it was never realized.

Anyway, we do think that by means of the general contact network, which is described in chapter 6 the results from this programme have been reasonable effected.